Search for Beyond the Standard Model Higgs Bosons

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ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

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Bundesministerium für Bildung und Forschung

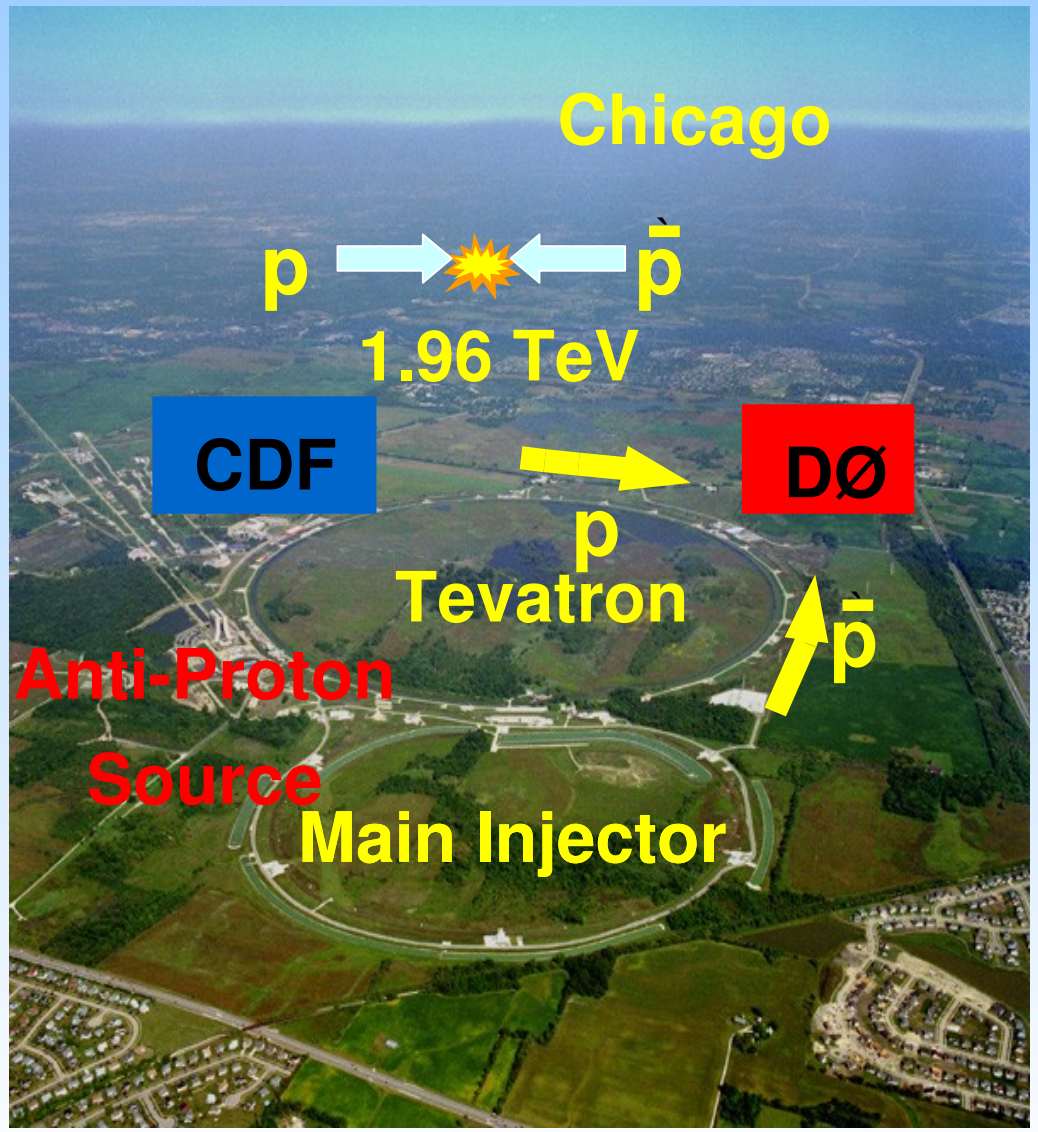
http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Outline

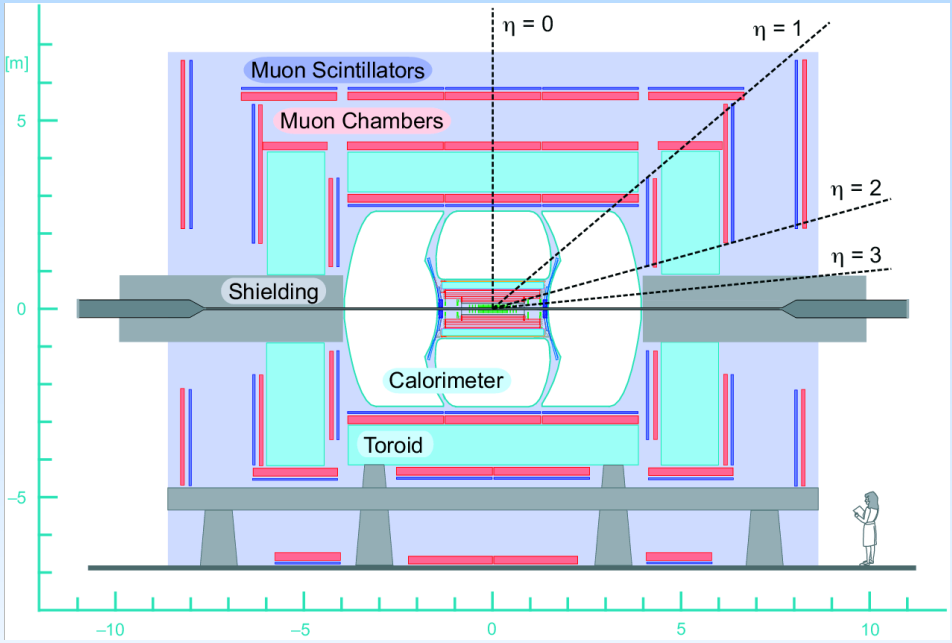
- Tevatron & DØ detector
- Higgs Sector in the MSSM
- Search for neutral MSSM Higgs bosons
  - Multi-b-jet events: $b(b)\Phi \rightarrow b(b)bb$
  - Tau lepton pairs: $\Phi \rightarrow \tau^+\tau^-$
  - Tau lepton pairs + 1 b-jet: $b\,\Phi \rightarrow b\,\tau^+\tau^-$
- Doubly charged Higgs bosons
- Fermiophobic Higgs bosons
- Conclusions & Outlook

Tevatron & DØ Detector

- Tevatron Run II 2001-2009/2010
- Center-of-mass energy: 1.96 TeV

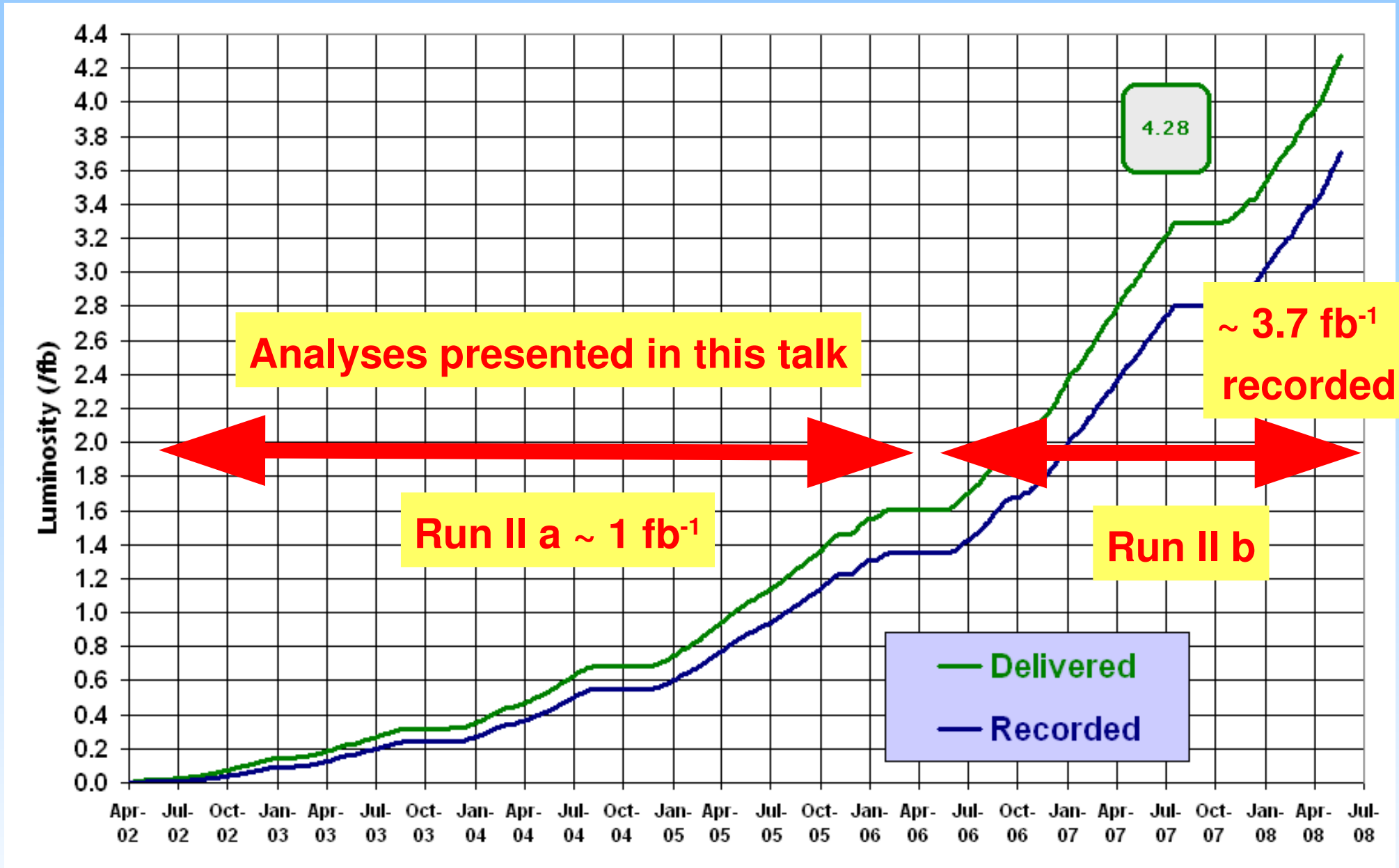


- Bunch spacing: 396 ns
- DØ detector
  - Multi purpose detector
  - ~4π coverage



$$\eta = -\log(\tan\theta/2)$$

Integrated Luminosity



~ 90 % Data taking efficiency

Higgs Sector in the MSSM

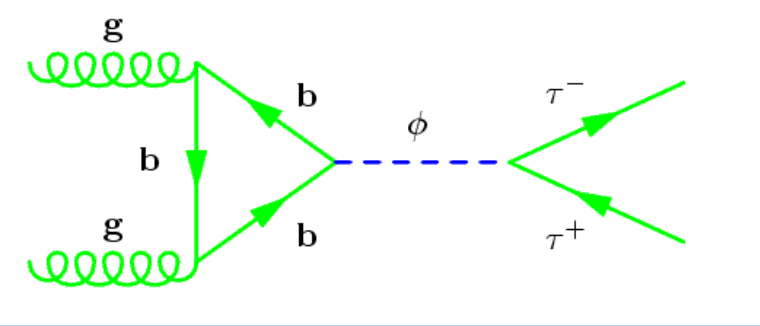
- Higgs sector in the MSSM is based on two complex Higgs doublets
- After electroweak symmetry breaking:
  - 2 charged Higgs bosons (H^+, H^-)
  - 3 neutral Higgs bosons ($h,H,A = \Phi$)
- At large $\tan(\beta)$ A is nearly mass degenerate with either h or H
  → cross sections can be added
- Higgs sector is fully specified at leading order using m_A and $\tan(\beta)$
- Consider two benchmark scenarios:
  - **m_h-max**: m_h close to the possible maximum for a given $\tan(\beta)$
  - **no-mixing**: vanishing mixing in stop sector → small m_h

	m_h-max	no-mixing
M_{SUSY}	1 TeV	2 TeV
X_t	2 TeV	0
M_2	200 GeV	200 GeV
μ	±200 GeV	±200 GeV
m_g	800 GeV	1600 GeV

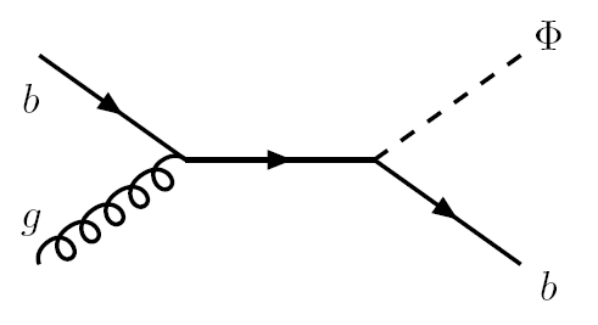
Neutral MSSM Higgs Boson Production and Decay

- Enhanced coupling to down type fermions leads to sizeable production cross section

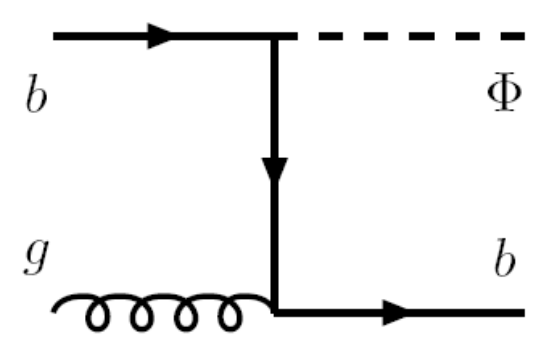
  → $\sigma \sim \tan^2(\beta)$ (at leading order)



- Dominant production modes at Tevatron
  - gg → Φ (Gluon fusion)
  - bg → bΦ (in association with b quarks)



- Leading decay modes:
  - Φ → bb (~90%)
  - Φ → $\tau\tau$ (~10%) small branching ratio
    BUT: Channel does not suffer from large multi-jet background

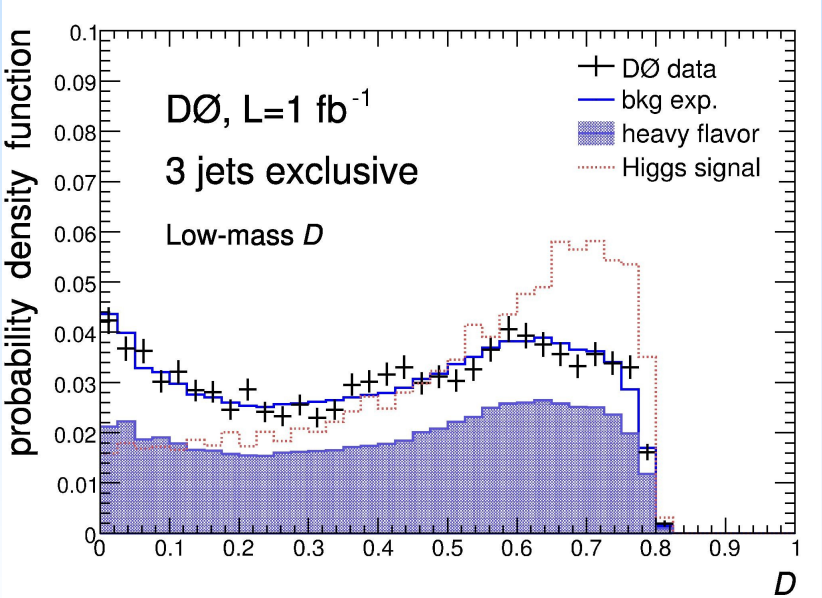


Φb(b) → bbb(b) - Analysis

- Data: 1 fb^{-1} recorded by 3-jet (p_T > 25, 25, 15 GeV) and b-jet triggers
- 3 b-tagged jets, p_T > 20 GeV, $|\eta|$ < 2.5 (b-tag eff. ~ 50%, mistag rate ~ 0.4%)
- 2 likelihood discriminators *D* (low-mass & high-mass Higgs, split at 130 GeV) based on $\Delta\eta$, $\Delta\phi$ and p_T balance in a pair of jets (...)
- Main background: QCD Multijet (simulated by Alpgen & Pythia (shower & hadroniza.))
  - Contributions from tt, Zbb, single top are negligible
- 3 b-tag background estimated using 2 b-tag data, shape estimated in likelihood-M(bb) plane:

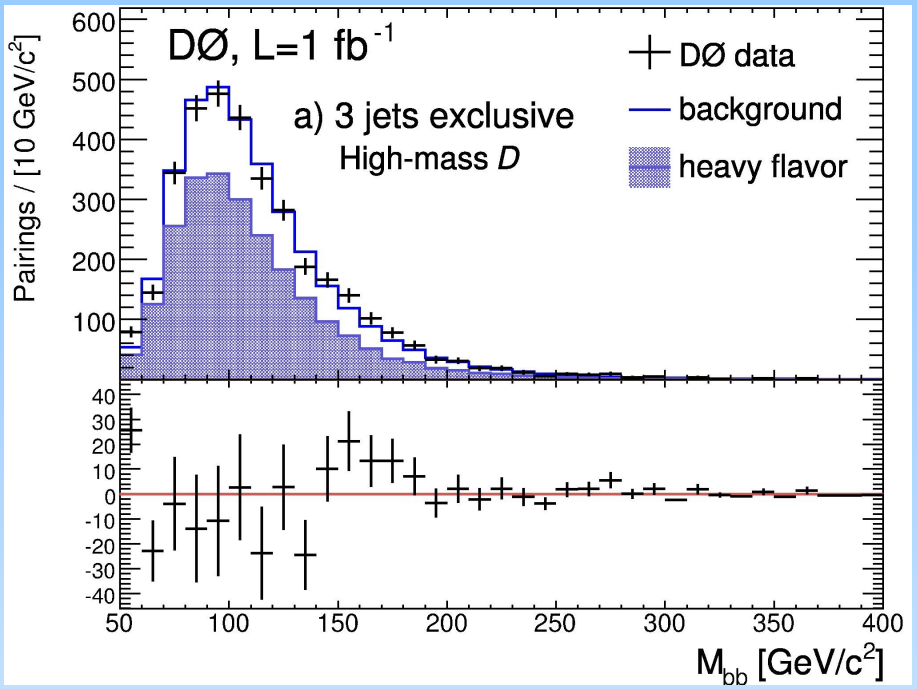
$$S^{exp}_{3\mathrm{Tag}}(\mathcal{D}, M_{bb}) = \frac{S^{MC}_{3\mathrm{Tag}}(\mathcal{D}, M_{bb})}{S^{MC}_{2\mathrm{Tag}}(\mathcal{D}, M_{bb})} S^{data}_{2\mathrm{Tag}}(\mathcal{D}, M_{bb})$$

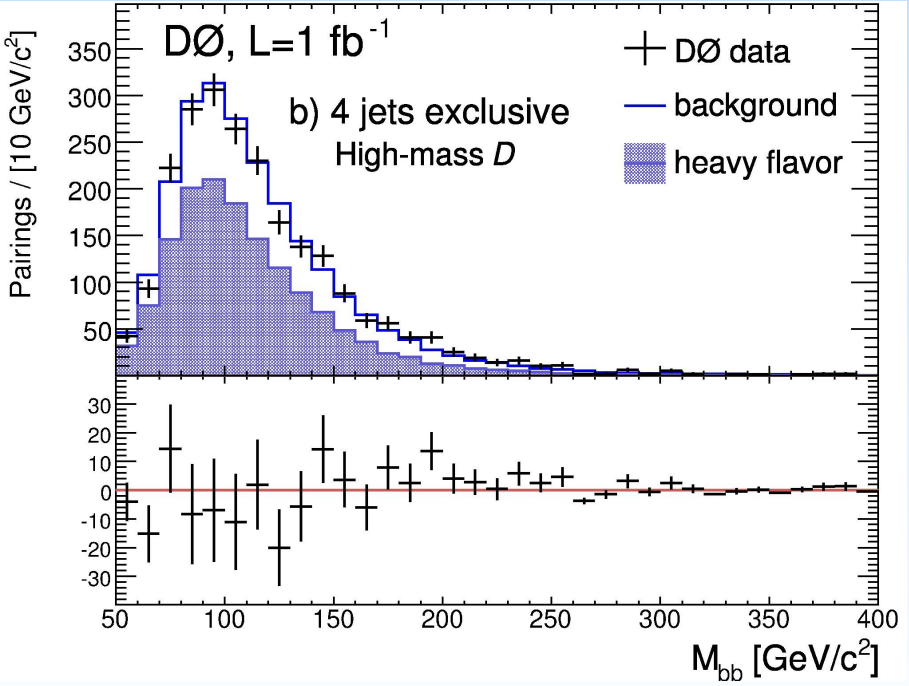
- Higgs signal: Pythia simulation corrected to match MCFM NLO XS and kinematic prediction in p_T and η of leading b-jet not from Higgs
- Optimal cut depends on Higgs mass: 0.25–0.60

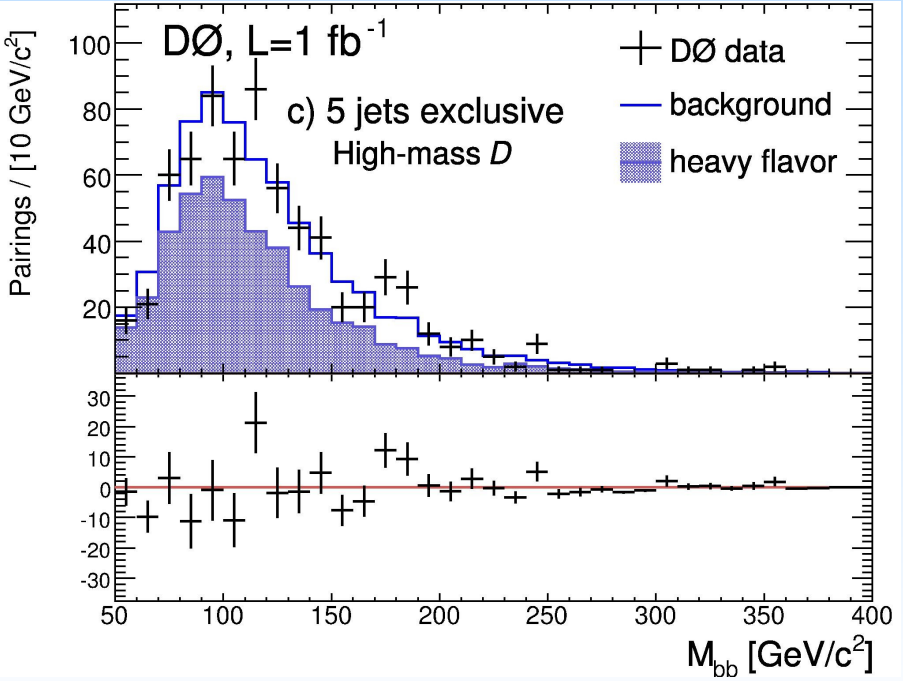


Φb(b) → bbb(b) - Analysis: M(bb) Distribution

- Data compatible with Standard Model
- Systematic uncertainty dominated by background composition (bbj/bbb)
- Signal efficiency in 3-jet sample: 0.3 % - 1.2 % for $100 < M_H < 200$ GeV



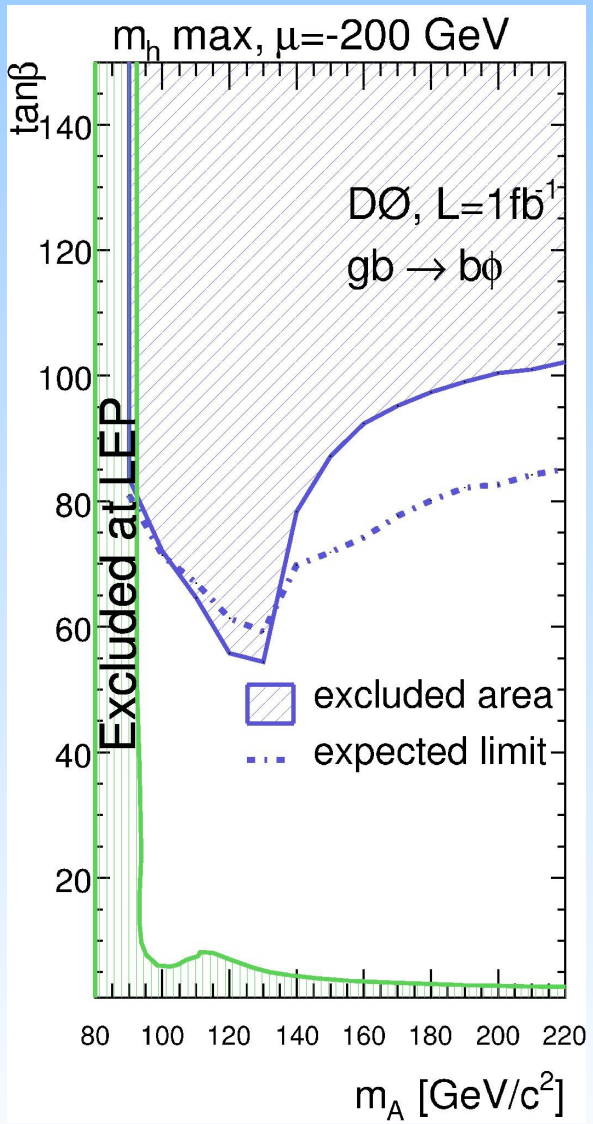


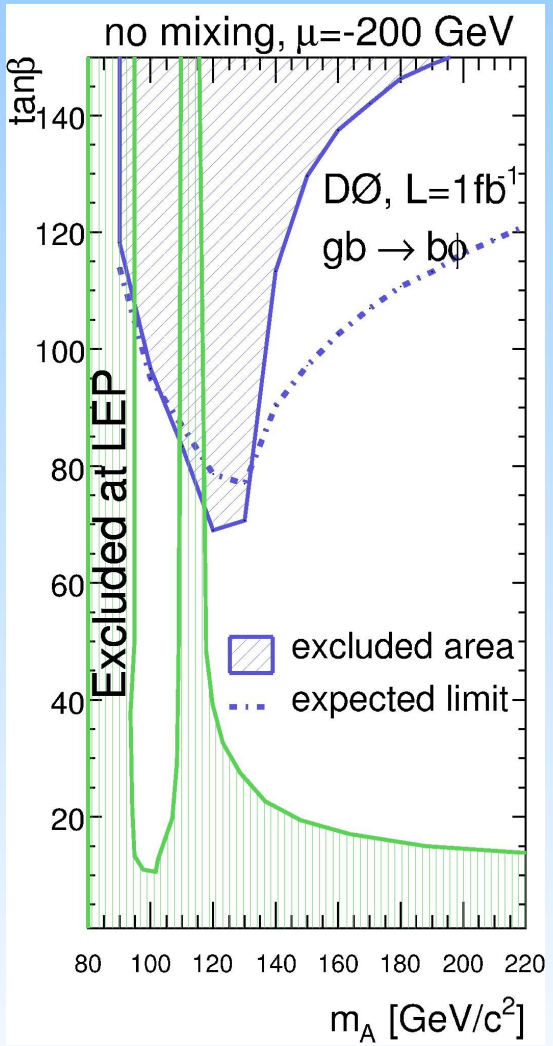


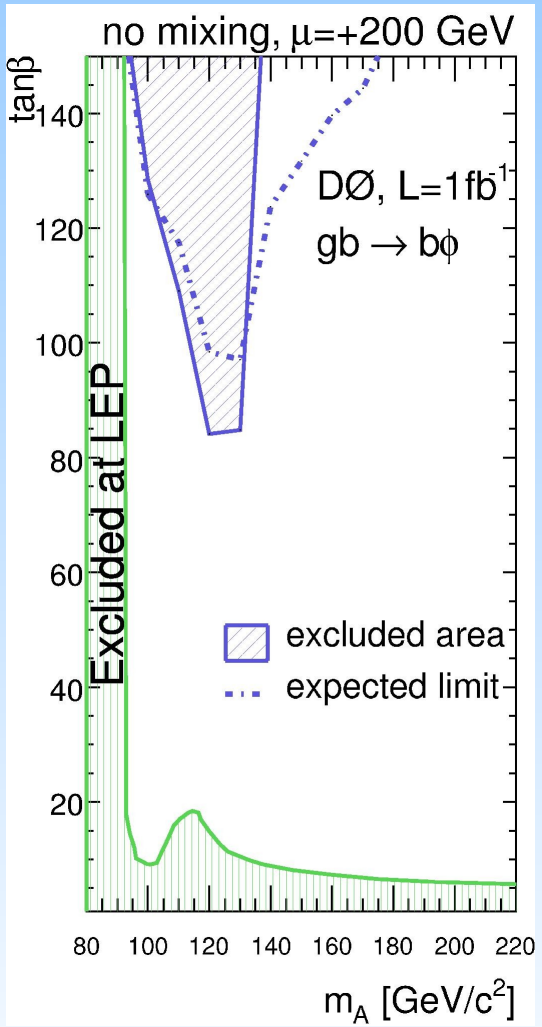
Interpretation of limit on σ X BR in the MSSM

- Limit based only on shape differences of background and signal
- Including Higgs width effects

Feynhiggs 2.6.3







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$\Phi \rightarrow \tau^+\tau^-$ - Analysis

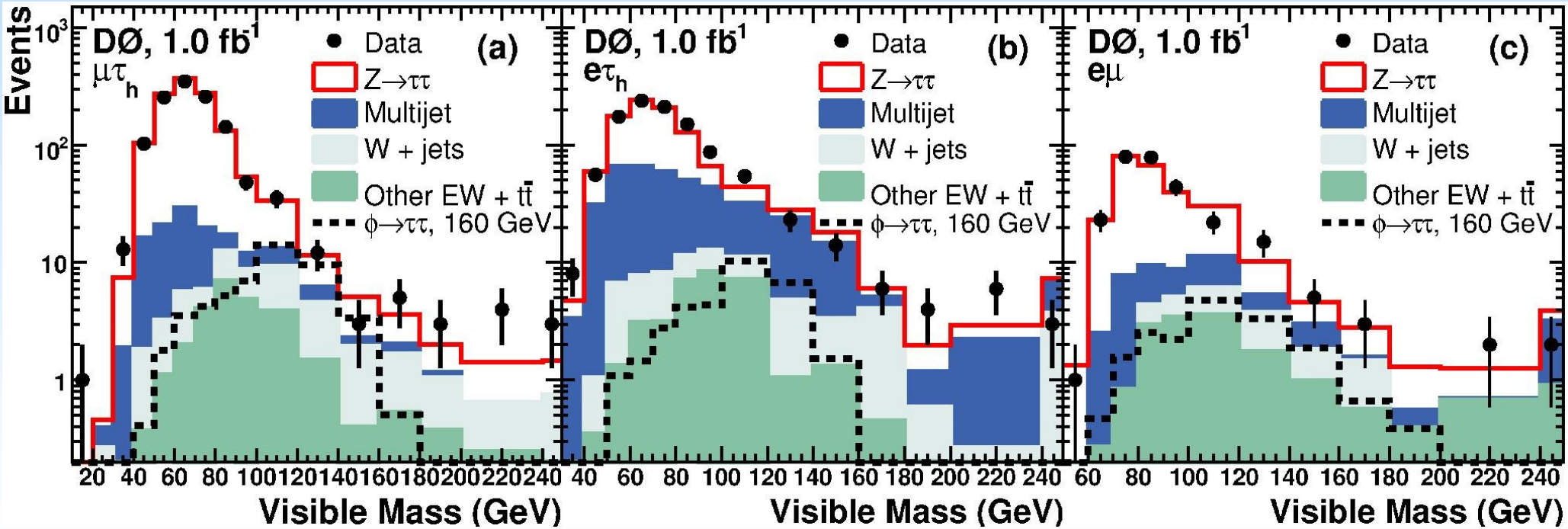
- 3 final states: **e+τ_h, μ+τ_h , e+μ** cover ~50% of total BR($\Phi\rightarrow\tau\tau$)
- Hadronically decaying taus: narrow isolated jets, identified using neural networks
- Data Sample, L = 1 pb^{-1}, recorded by Electron/Muon Trigger
- Standard Model backgrounds from Pythia: Z→$\tau\tau$ (irreducible), Z/γ^*→ee/$\mu\mu$, W→lep+ν (only shape from Pythia), Di-boson
- Multi-jet background determined from data:
  - e+τ_h final state: like sign events
  - μ+τ_h / e+μ, final state: inverted lepton isolation criteria
- Main selection criteria of tau analyses (e + μ slightly different)
  - Isolated leptons, p_T thresholds: e/μ+τ_h: 15/15 + 16.5 GeV, e+μ: 12 + 10 GeV
  - m_T^{lep} < 40 GeV, 50 GeV $m_T^{lep} = \sqrt{2\, p_T^{lep} \not{E}_T (1 - \cos\Delta\phi)}$
  - 2d cut in Δφ(e/μ,MET)-Δφ(τ,MET) plane

$\Phi \rightarrow \tau^+\tau^-$ - Results

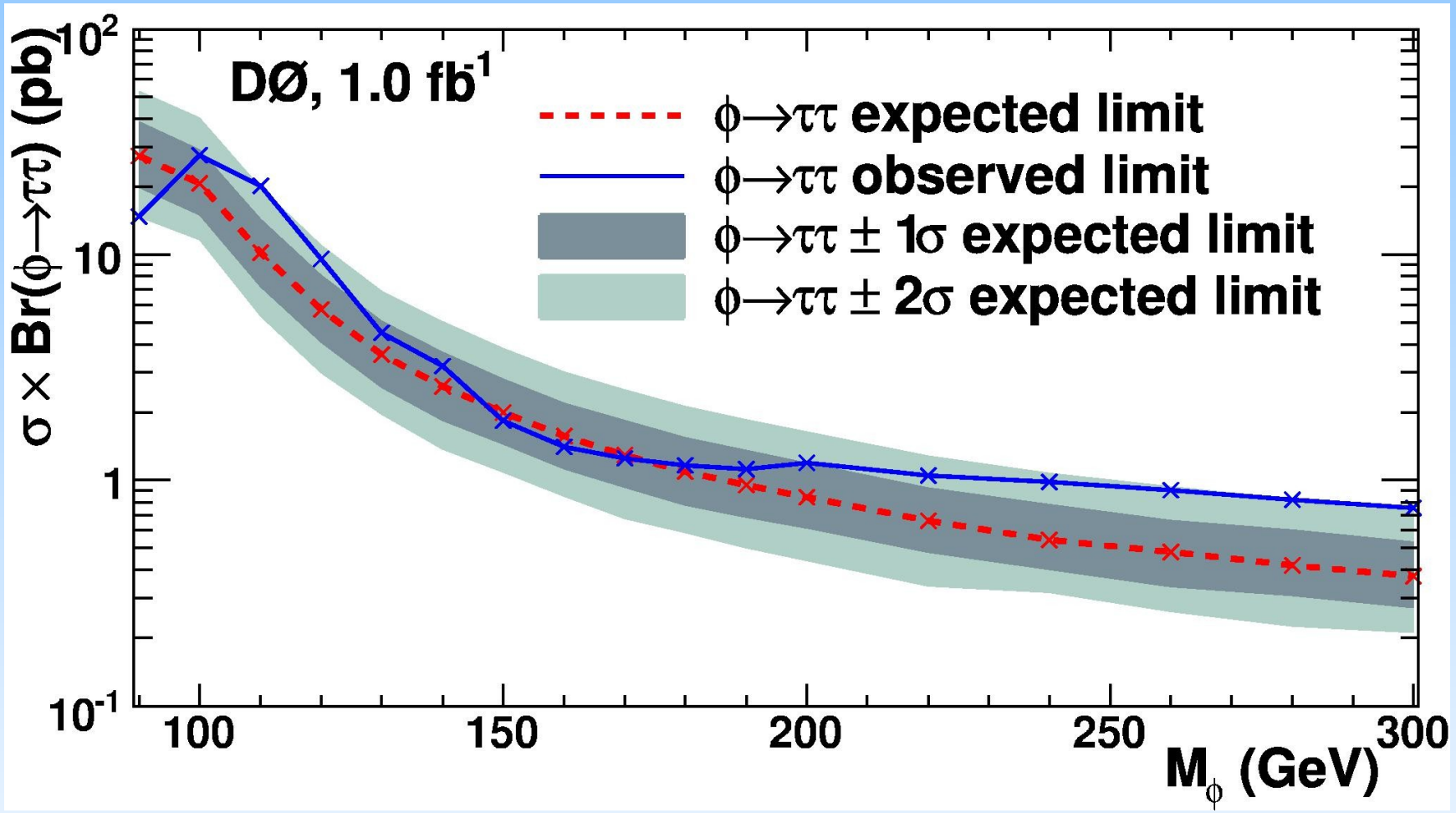
- Signal expected as enhancement over background in distribution of visible mass

$$M_{vis} = \sqrt{P_{vis}^{\tau_1} + P_{vis}^{\tau_2} + \not{P}_T}$$

- Main systematic uncertainties: modeling of multijet background (4-40 %), Normalization of W-background (6-15 %), Lepton Identification (2-10 %)
- Shape uncertainty caused by energy scale parameterized as function of M_{VIS}
- No significant excess in data → Set limit on σ x BR at 95% CL



$\Phi \rightarrow \tau^+\tau^-$ - Results

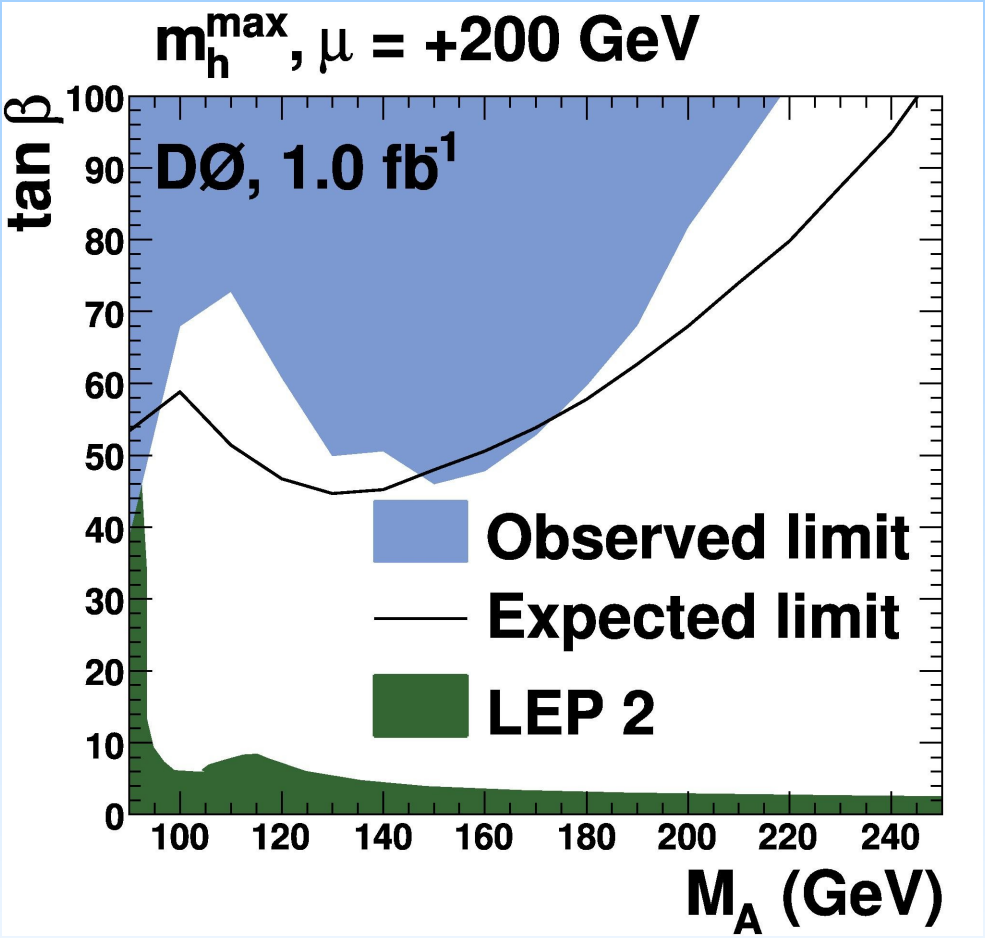


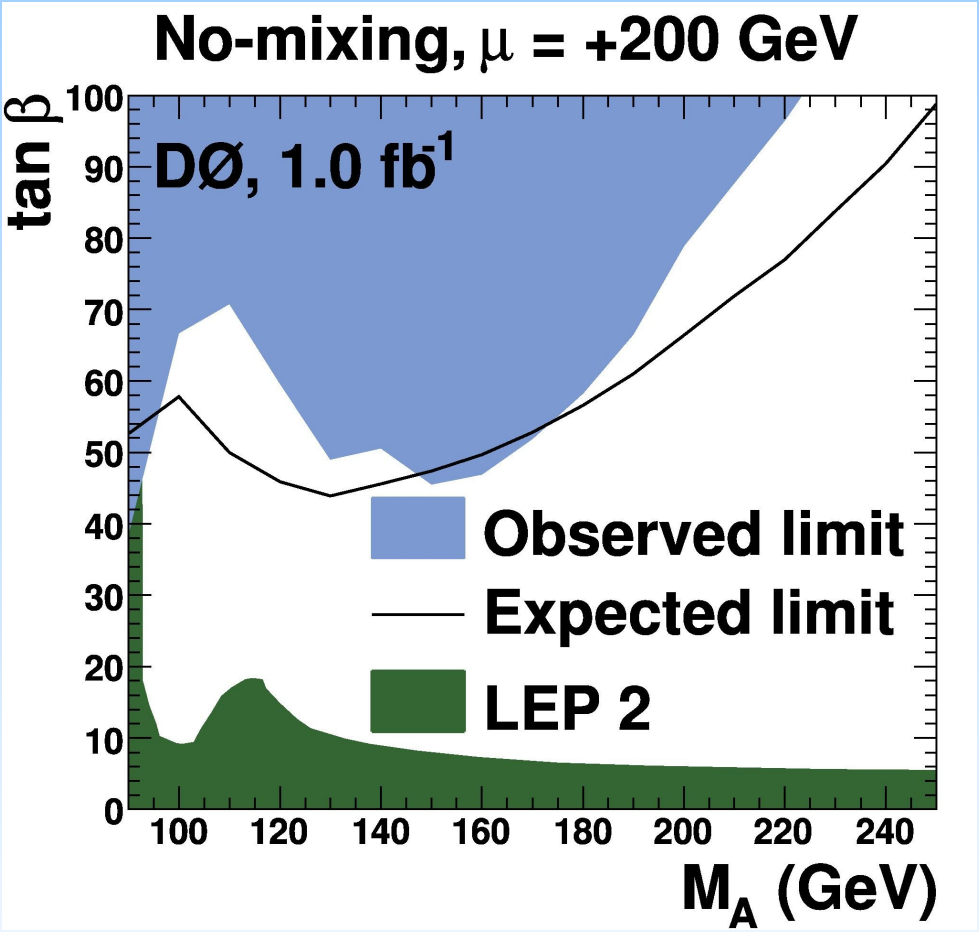
- ~ 2 σ excess at large Higgs boson masses due to $\mu+\tau$ channel (M_{VIS} > 160 GeV)

$\Phi \rightarrow \tau^+\tau^-$ - Interpretation in MSSM

- Impact of increasing Higgs width has been studied in detail
  - Negligible in considered scenarios

Feynhiggs





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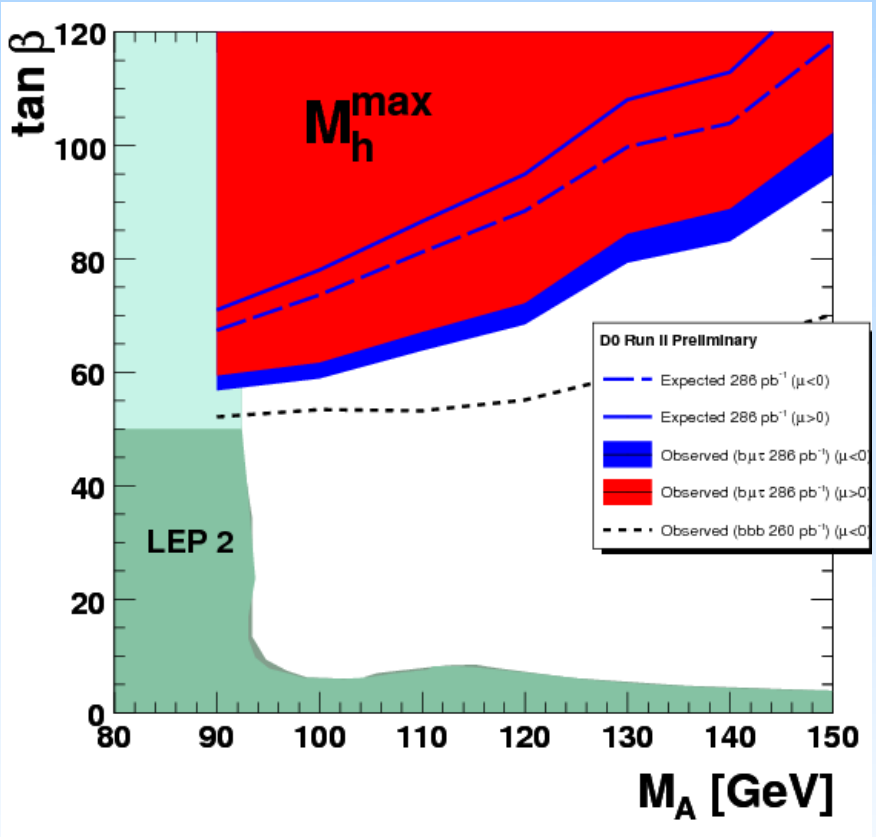
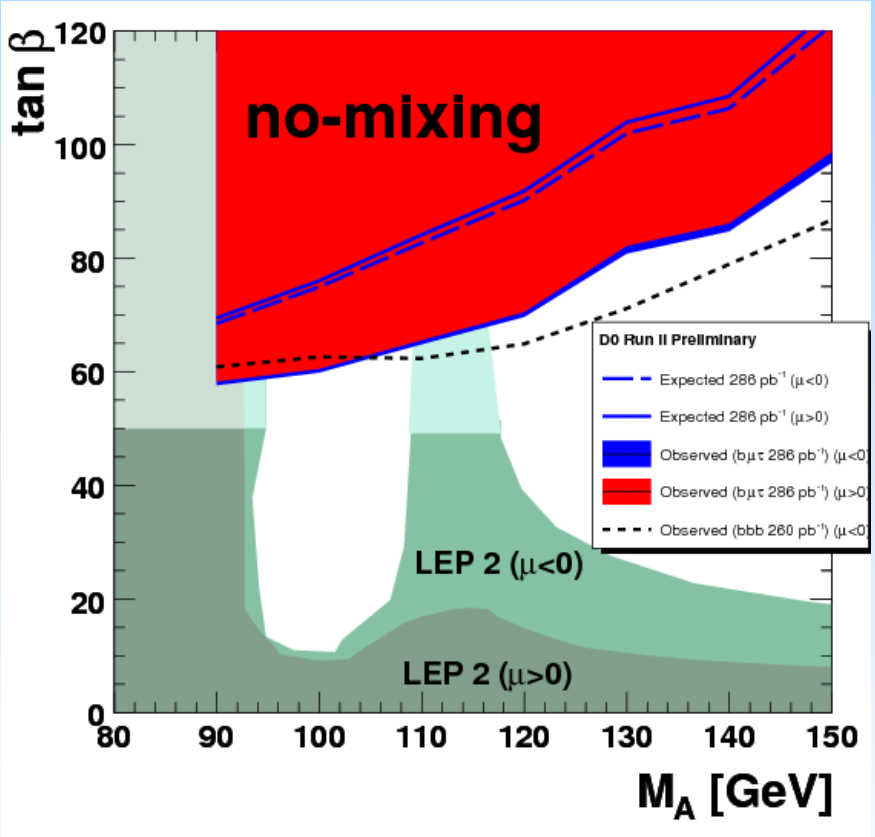
$b\,\Phi \rightarrow b\,\tau^{+}\tau^{-}$ - Analysis

- Isolated muon p_T > 12 GeV, tau p_T > 5 GeV, b-jet p_T > 15 GeV
- Data L = 0.3 fb^{-1}, single muon trigger
- Update based on available Run II data well advanced based, not yet approved by DØ Collaboration

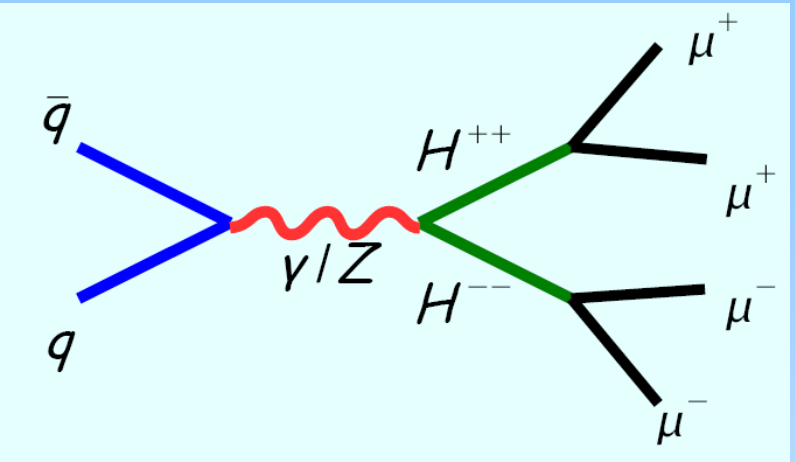


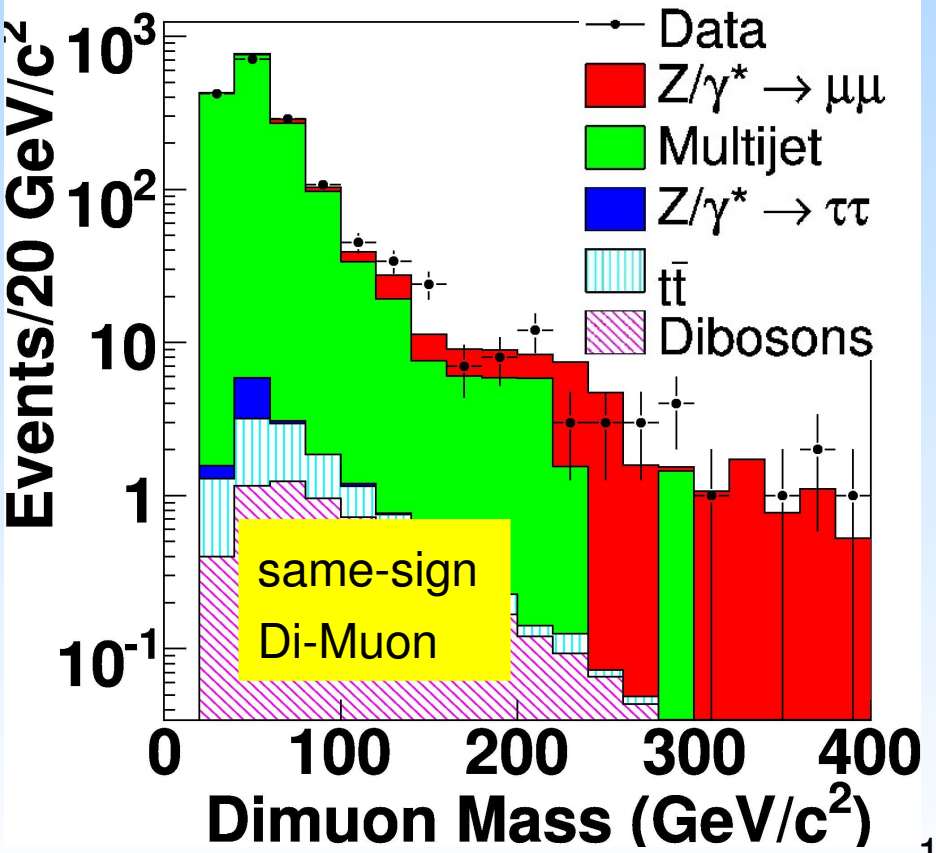


http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Search for Doubly-Charged Higgs Bosons

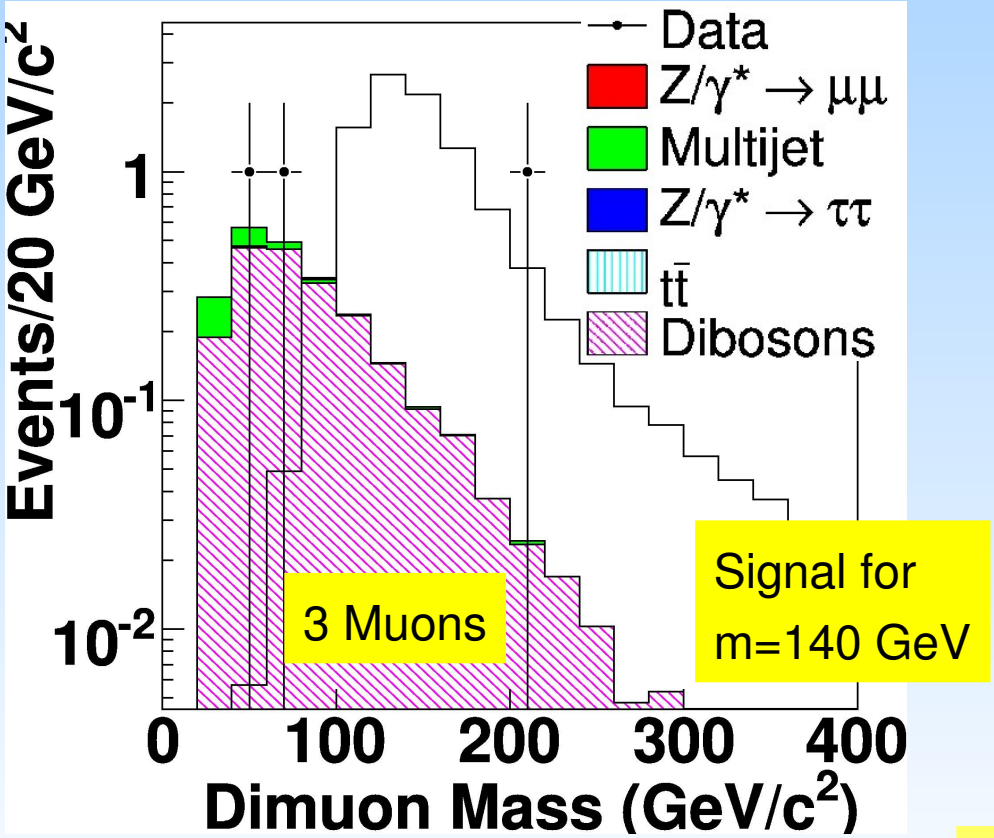
- Doubly-charged Higgs bosons appear in
  - Left-right symmetric models
  - Higgs triplet models
  - Little Higgs models
- Data Sample: L = 1 fb^{-1}, muon trigger
- Strategy:
  - 3 isolated muons p_T > 15 GeV
  - One pair of like sign muons
  - $\Delta\phi(\mu_1,\mu_2) < 2.5$
- Low Standard Model background
- Multi-jet background estimated from data

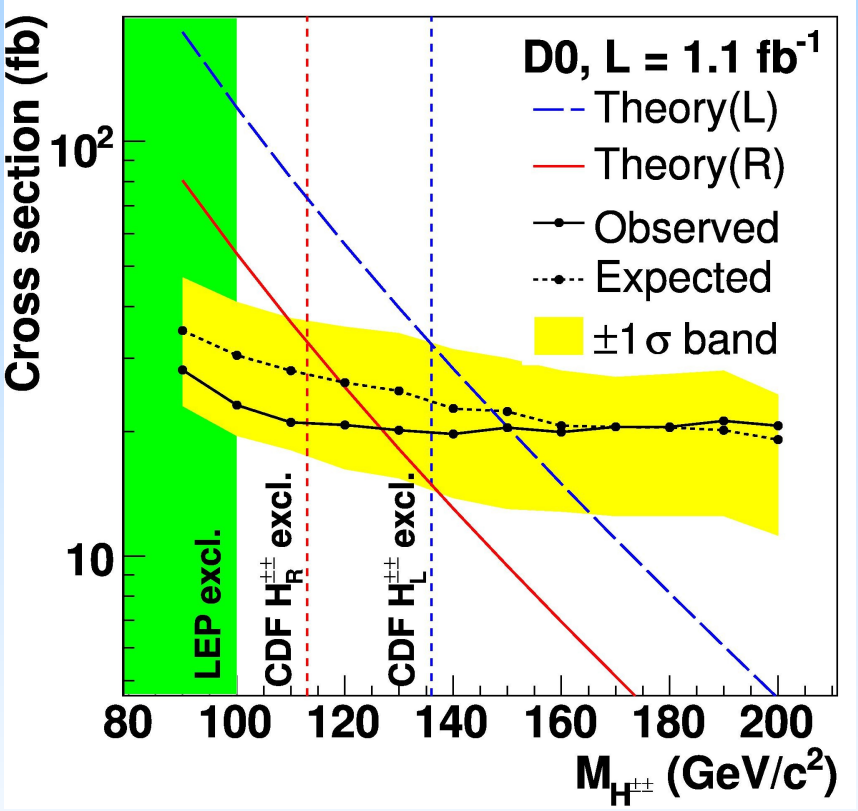




Search for Doubly-Charged Higgs bosons

- Signal efficiency 32 - 34 % (nearly independent of Higgs boson mass)
- Systematic uncertainty dominated by charge misidentification (20 %)
- 3 data events, 2.3 ± 0.2 expected from Standard Model (2.1 from WZ and ZZ)
- Lower limits on $M(H^{\pm\pm})$ 150 GeV (left handed) and 127 GeV (right handed)





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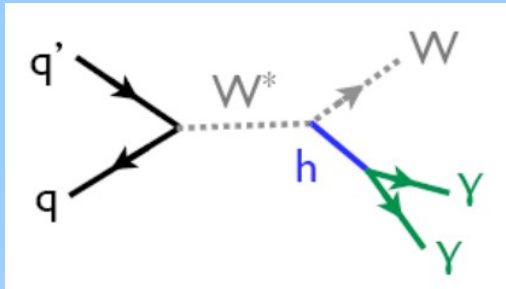
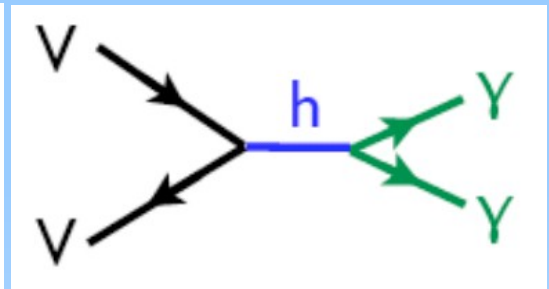
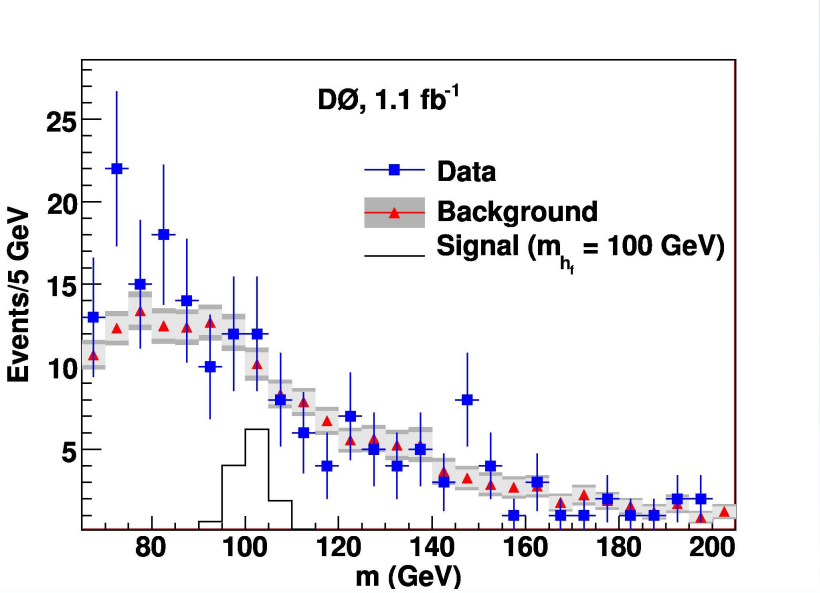
Search for $h_f \rightarrow \gamma\gamma + X$

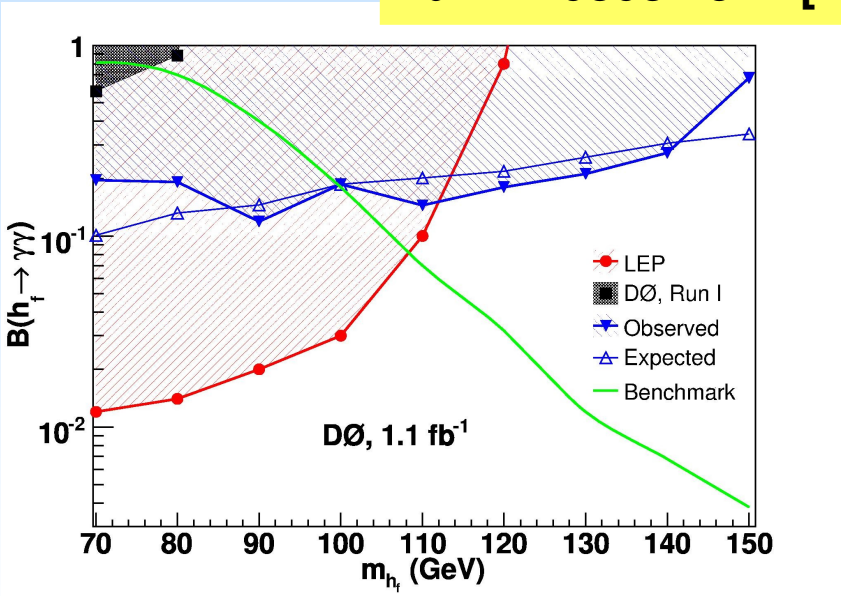




- Fermiophobic Models: suppressed Higgs-fermion couplings
- Benchmark model:
  - Standard Model couplings to W,Z; no couplings to fermions
  - M_H < 100 GeV BR(H-$\gamma\gamma$) dominates
- Data L = 1 fb^{-1}, EM trigger, $p_T(\gamma)$ > 25 GeV, background form direct di-photon processes & jets misidentified as photon suppressed by $p_T(\gamma\gamma)$ > 35 GeV
- Lower Higgs mass limit: M_H > 100 GeV at 95 % CL

Submitted to PRL, arXiv:0803.1514 [hep-ex]





Summary & Outlook

Summary

- DØ searches for beyond the Standard Model Higgs bosons in various scenarios in the mass range from 100 to 300 GeV
- Improved calibrations and analysis techniques
  => In most channels, exclusion limits improved more than $\sqrt{L}$
- Run II a data probe MSSM parameter space down to tan β ~ 40-50

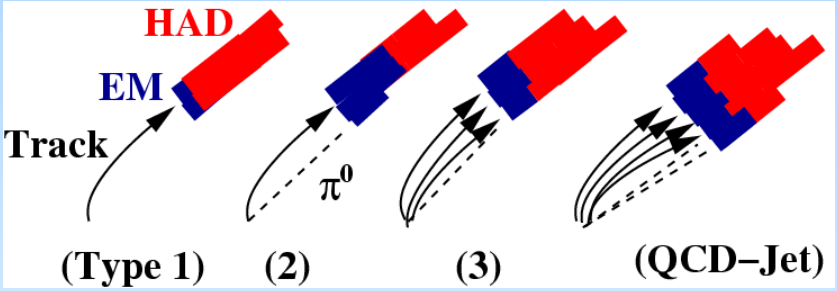
Outlook

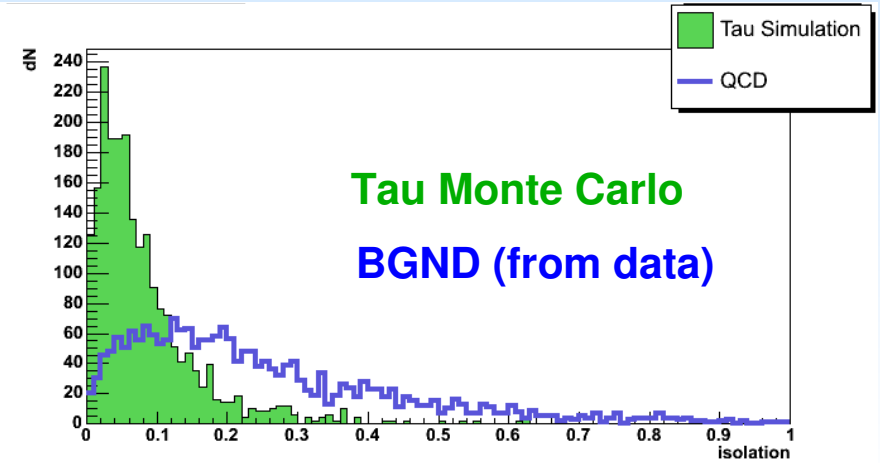
- Run II b data are being analyzed
- Expect updated results for BSM Higgs boson searches soon
- Final data set expected to be ~7 fb^{-1} per experiment

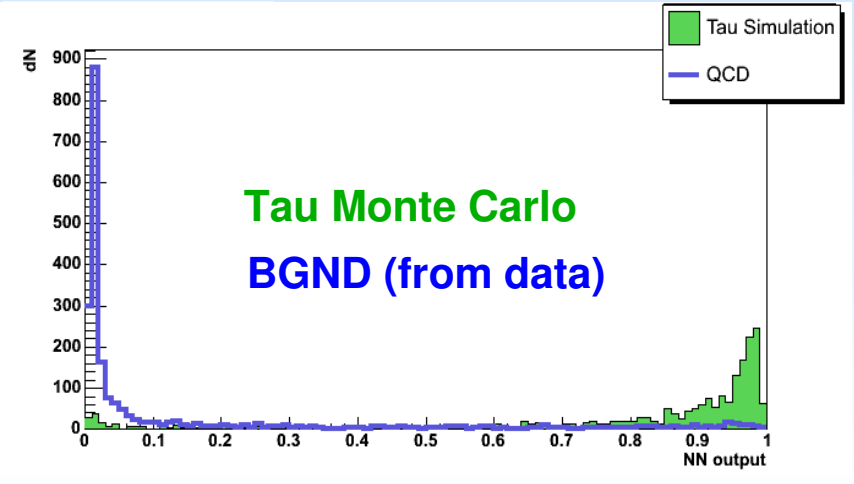
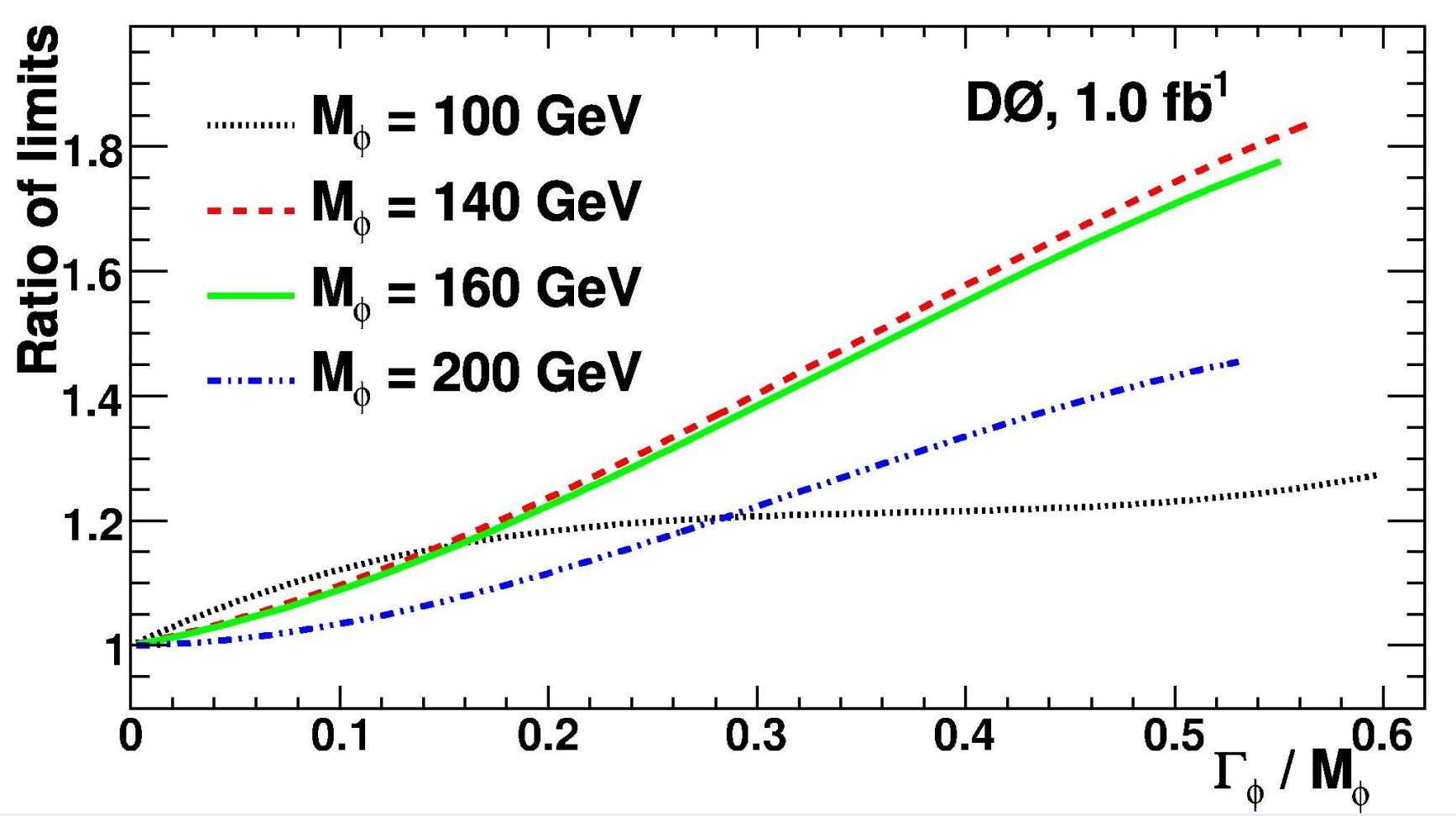
Backup

Tau Identification at DØ

- Tau = narrow isolated jet with low track and π^0 multiplicity
  - Tau candidates are divided into 3 types:
    - **Type 1**: one track, calorimeter cluster **without** EM subcluster (π-like)
    - **Type 2**: one track, calorimeter cluster **with** EM subcluster (ρ-like)
    - **Type 3**: 2 or 3 tracks consistent with the tau mass, calorimeter cluster (3-prong)
- Tau identification based on neutral network
  - Non-linear correlations between variables taken into account
  - Discriminating variables: profile, isolation in calorimeter and tracker, ...







$\Phi \rightarrow \tau^+\tau^-$ - Higgs Width